VMAP
Vegetation Management Alternatives Program

A Guide to Opportunities

Mechanical Site Preparation and Vegetation Management

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Introduction

Successful silvicultural prescriptions require a clear definition of objectives and an accurate assessment of site and stand conditions that will influence the establishment and growth of the new crop. The major constraints likely to interfere with successful crop establishment must be identified, and a course of action to reduce their impact must be outlined (Sutton 1989).

Mechanical site preparation* involves the use of machinery to prepare favourable environments for crop trees (Ryans and Sutherland 2001). It is one element of a silvicultural prescription that is used to create desirable microsites at a prescribed spacing and abundance and to remove any physical obstructions (e.g. harvest debris) that may interfere with renewal treatments.

Selecting a mechanical site preparation treatment is based on a number of considerations (Johnson *et al.* 1993). One critical consideration is the post-treatment effect on the vigour and abundance of non-crop vegetation. A mechanical site preparation plan should consider equipment options, application techniques, and the timing of treatments to reduce the impact of competing non-crop vegetation on crop trees.

This note, which is part of the *Vegetation Management Alternatives – A Guide to Opportunities* publication series, discusses the application of various mechanical site preparation treatments, their influence on microsite modification, and the implications for vegetation management.

* Scarification, a term often used interchangeably with site preparation, is defined as a method using mechanical site preparation techniques to prepare a site for regeneration by natural means (OMNR 1997).

Desirable Microsites and Crop Tree Establishment

The seedling environment may be considered at various scales (Stathers *et al.* 1990). Regional climate, landform and soil characteristics determine which species and seed source is best adapted for use in regenerating a particular stand. Within a stand, variations in local climate and soil conditions (e.g. texture, depth, and moisture regime), influenced by aspect and topography, help to define the optimum location for the establishment and growth of various species. Finally, the successful establishment and growth of an individual plant depend on the environmental conditions and resources associated with the immediate microsite.

Soil moisture and temperature are two of the most important factors associated with the microsite that influence the survival and growth of tree seedlings during the establishment phase (Adams *et al.* in prep.). The small size of the seedlings during this phase magnifies the impact of small changes in these factors. Depending on site conditions, microsites may be modified or created to either conserve or remove excess water. Microsites can also be altered to facilitate soil warming to improve seedling growth (particularly root growth) or to reduce temperature extremes at the soil surface that could damage or kill seedlings (Ryans and Sutherland 2001).

Mechanical site preparation is used to create desirable microsites for crop trees. (photo by R.G. White)

A common goal of mechanical site preparation in northern Ontario is to produce mineral soil microsites that can support conifer regeneration by planting or seeding (Ryans and Sutherland 2001). Site preparation in advance of planting may be used to remove or redistribute duff layers so that roots of the planted seedling are placed directly into the mineral soil. Reducing competing vegetation and realigning or redistributing slash that interferes with crop tree establishment or impedes worker access are often included as treatment objectives. Site preparation for seeding is used to create or increase the amount of well-distributed receptive seedbeds that are able to maintain adequate soil moisture near the soil surface during the critical germination and early establishment phases (Adams *et al.* in prep.). Because microsite conditions are so critical for seeding success, an estimate of the distribution and abundance of acceptable seedbeds can be used to predict regeneration stocking results (Regniere 1982).

An understanding of seedling establishment, survival and growth on particular microsites is needed to select the most appropriate site preparation method (McMinn 1984). The optimum microsite for a species may vary by site. For example, exposed mineral soil on dry sites provides a good seedbed for jack pine seeding (OMNR 1997). However, as the soil moisture regime increases from moderately fresh to moderately moist, the depth of the organic layer over mineral soil where jack pine will establish from seed also increases (Adams *et al.* in prep.).

The preferred location for establishing the crop tree within a microsite "profile" is also site dependent. Raised profiles may be preferred in cool, moist conditions, while depressed microsites may be advantageous in drier conditions. Due to these variables, crop tree performance may be influenced by seedling position within the site preparation profile or even by the orientation of the site preparation pattern (Bedford and von der Gonna 1994).

Depending on the site, mechanical site preparation may involve the deliberate manipulation of site factors to improve the following conditions (after Daniel *et al.* 1979, McMinn and Hedin 1990):

- availability of soil moisture
- amount of solar radiation reaching the microsite
- soil temperature ranges and averages
- soil physical properties, such as compaction and aeration
- soil nutrient availability
- distribution and alignment of woody debris
- amount and proximity of competing vegetation
- potential effects of insects, diseases, and animals

The site should be viewed both pre- and post-harvest to assess which factors may significantly constrain successful regeneration and to identify opportunities for using mechanical site preparation to alleviate those constraints (Sutton 1989). Prior to harvest, a forest ecosystem classification may be used to describe the site (e.g. soil texture, depth, and moisture regime, depth of organic matter, rockiness, and potential for post-harvest vegetation development) and to identify conditions that may require modification to improve seedling establishment (e.g. seedbed conditions and understorey competition). After harvest, the site should be visited to determine the need for treatments to increase the abundance and distribution of desirable microsites and to identify conditions that may limit the effectiveness of certain types of site preparation equipment (e.g. residual trees, high stumps and slash loadings). (Sutherland and Foreman [1995] provide examples of this pre- and post-harvest analysis.)

This information may be used to prepare a site-specific mechanical site preparation prescription that would include treatment objectives and a rationale for equipment selection. Since site conditions are rarely uniform across an area, the selected site preparation method should be appropriate for use on most of the site to create the proper amount and distribution of desired microsites at a reasonable cost.

Mechanical Site Preparation Effects on Non-crop Vegetation

Mechanical site preparation treatments are designed to enhance conditions for establishing and growing crop trees, which may include removing or reducing existing competitive vegetation. However, site preparation treatments may inadvertently and somewhat unpredictably create conditions that promote the establishment and vigorous development of non-crop species on treated areas. To prevent difficult vegetation management conditions, the role of site preparation as part of an integrated vegetation management strategy should be considered.

Site preparation is generally a far more effective and economical means to control colonization by non-crop species than release treatments later in the stand's development (Wagner *et al.* 2001). If the response of non-crop vegetation to site preparation treatments is anticipated, treatments may be selected or modified to prevent the development of competition problems that may be costly or difficult to remedy. Early control of competitors using site preparation to delay or prevent their establishment also prevents crop tree growth losses that would occur if release treatments were applied later (Wagner *et al.* 1996, 2001).

The interaction of the crop trees with other vegetation may be either beneficial or negative, and this relationship may change over time depending on the autecology of the respective species and differences in site quality (Bell 1991, OMNR 1997, Sutherland and Foreman 1995). Beneficial aspects of non-crop vegetation may include providing light shade that reduces air and soil temperatures around young seedlings and capturing and storing nutrients that may have otherwise been lost from the site following disturbance. However, non-crop vegetation is most often detrimental to crop tree survival and growth and competes for moisture, nutrients, light, and space (Bell 1991).

Plants differ in their ability to colonize and occupy a disturbed site. The important properties of a plant that determine its ability to "capture" the resources of a site are its abilities to reproduce quickly to form dense stands and to grow rapidly once established (Newton 1981). On mechanically prepared microsites, the ability of non-crop plants to capture resources is dependent on the reproductive strategy of the species, the productivity of the site for that species, the timing of the site preparation treatment, and the extent of modification of the organic and mineral soil layer (Bell 1991, OMNR 1997, Sutherland and Foreman 1995).

Various competitor species may invade or encroach on microsites created for reforestation. (photo by R.G. White)

Reproductive Strategy

Reproductive strategies for competing vegetation may be categorized as follows (Bell 1991):

- Vegetative (asexual) reproduction:
  - From roots: root suckers, rhizomes
  - From shoots: root collar or lower stem sprouts, layering, stolons
- Sexual reproduction:
  - From seed: soil seed bank, current seed crop

Almost all plants reproduce both vegetatively and sexually, although one method may predominate (Bell 1991, OMNR 1997). The autecology and reproductive strategies of a number of plant species are documented in various guidebooks (Haeussler and Coates 1986, Bell 1991, Buse and Bell 1992, Arnup *et al.* 1995, OMNR 1997).

Vegetative reproduction is generally more successful than sexual reproduction in the rapid colonization and recovery of plant cover immediately following a disturbance. For example, sprouting from root suckers connected to parent plants (with established food reserves and water supply) facilitates the growth of site-adapted individuals without depending on seed supply, dispersal, seed viability, seedbed conditions or germination (Zasada 1971). Weed species that primarily reproduce by vegetative means generally have an advantage in "pre-emptively" capturing the site resources from slower-growing conifer crop trees, unless vegetation management treatments are applied (Newton 1981).

Reproduction from seed permits plant species that are seemingly rare or absent in mature forest stands to become established following disturbance of the forest floor (OMNR 1997). Seeding regeneration strategies may be categorized as involving the "current seed crop" and/or the "soil seed bank" (Bell 1991). Non-crop species that colonize a site using seed from a current seed crop usually produce large numbers of seed at an early age and often have light windblown seed that can be transported "on site" from a distance. Treatments that improve seedbed conditions for crop species (e.g. improve moisture retention) often improve seedbed conditions for these invading "weed" species as well. Species that "seed bank" their propagules have seed that may remain viable in the upper soil and humus layers for many years. The variety and numbers of seed from seed bank species varies greatly from site to site (Kramer and Johnson 1987). The potential for weeds from the soil seed bank to invade a site may be predicted using knowledge of the stand's history of treatments, its successional development and the longevity of weed seeds in the soil (Conn and Farris 1987).

Knowing a species' primary mode of reproduction can help predict its response to mechanical disturbance. For vegetative reproduction, the depth and location of the parent root systems relative to the depth and location of the disturbance is a key consideration (Buse and Bell 1992, Sutherland and Foreman 1995). Disturbances that uproot parent plants may provide some control of non-crop species. Treatments that merely sever a part of the plant without removing reproductive structures (i.e. root suckers, rhizomes, root collar sprouts) may allow re-establishment. If a weed species reproduces annually or biannually using short-lived seed, the timing of treatments to reduce weed seed production for the current year may reduce re-establishment (OMNR 1997). For seed-banking species, site preparation treatments can be used to relocate or remove some of the seed on the forest floor. However, site preparation treatments often improve conditions (especially temperature and moisture regime), resulting in better germination and survival of the remaining seeds (Roberts and Dong 1991). Table 1 summarizes the relative influence of soil disturbance from mechanical site preparation on non-crop vegetation with different reproductive strategies.

Site Productivity

Site conditions will influence the response of vegetation to disturbance by mechanical site preparation. As site quality improves for the crop species, conditions often improve for other less desirable species (Newton 1981). As a result, the most productive sites also have the most severe competition problems in terms of diversity, vigour, and abundance. The ability of a weed species to respond to injury also improves on better sites. However, less productive sites are generally more stressful for young crop trees and even small amounts of non-crop vegetation may reduce crop tree survival and growth (Wagner *et al.* 2001).

On fertile sites, mechanical site preparation alone may not be sufficient to suppress weed species and allow for the establishment and survival of the crop trees (Walstad *et al.* 1987). On less productive sites, however, site preparation objectives may be achieved during harvesting. For example, on some wetter sites, full-tree harvesting in the winter may compact the sphagnum layer sufficiently to create favourable seedbeds for black spruce regeneration without creating severe competition problems (OMNR 1997).

Site preparation treatments should not reduce site quality. Excessive and/or severe site disturbances or removal of topsoil, particularly on coarse-textured or shallow soils, may reduce site quality and hamper growth of crop trees (Sutherland and Foreman 1995). Forest humus is a key component of forest ecosystems and contributes to the site's nutrient status. Some humus forms are inherently more susceptible to mechanical disturbances than others, and measures should be taken to minimize disturbance and conserve organic layers (Sims and Baldwin 1996).

Table 1. Relative influence of soil disturbance on non-crop vegetation (from Ryans and Sutherland 2001).

Legend		Vegetative Reproduction			Sexual Reproduction	
Effect on competing vegetation:		From shoots	From roots		Wind-borne	Seed bank
⬆⬆ Promotes strongly ⬆ Promotes □ No effect ⇩ Discourages ⇩⇩ Discourages strongly Organic Mineral		(e.g. beaked hazel, green alder, Labrador tea, mountain maple, red aster, dogwood, white birch, willow)	in organic layer (e.g. blueberry, blue-joint grass)	in mineral soil (e.g. prickly wild rose, poplar, wild red raspberry, willow)	seed (e.g. blue-joint grass, fireweed, poplar, white birch)	(e.g. blueberry, pin and choke cherry, prickly wild rose, red aster, dogwood, wild red raspberry)
All soils						
Undisturbed mature stand		□	□	□	□	□
Upland mineral soils						
Overstory removed, organic and mineral layers undisturbed (e.g. cutover)		⬆⬆	⬆	⬆	□ to ⬆ [a]	⬆
L layer and part of F layer removed or displaced (e.g. shallow screef)		⬆	⬆	⬆	⬆	⬆⬆
LFH removed, mineral soil intact (e.g. screef)		⇩⇩ to ⇩ [b]	⇩	⬆⬆	⬆⬆	⇩
LFH removed, some mineral soil removed (e.g. deep screef)		⇩⇩	⇩⇩	⇩⇩ to ⇩ [c]	⬆⬆	⇩⇩
LFH removed, mineral mound on mineral soil		⇩⇩	⇩⇩	⇩⇩ to ⇩ [d]	⬆	⇩⇩
LFH and mineral layers inverted (mineral mound on organic layer)		⬆ to ⬆⬆	⇩ to ⬆ [e]	⇩ to ⬆	⬆	⇩ to ⬆ [f]
LFH and mineral mixed (e.g. tilling) [g]		⇩ to ⬆	⇩ to ⬆	⇩ to ⬆	⬆⬆	⬆⬆
Lowland organic soil [h]						
Part of Of removed (e.g. by shearblading)	Of Om Oh	⇩ [i]	⇩ to ⬆ [i]	N/A	⬆	⬆
Drainage of layer (e.g. by ditching)	Of Om Oh	⬆	⬆	N/A	□	⬆

[a] Will promote if organic layer is shallow or moist (upland organic horizons: L-litter, F-fermentation, H-humic).
[b] Control of sprouting is improved for species that tend to root in the organic layer.
[c] Control of sprouting depends on removal of root systems.
[d] Control depends on removal of root systems below ground and mineral mound sufficiently deep to suppress sprouting.
[e] Control of sprouting increases with increased depth capping.
[f] A thin cap of mineral soil tends to encourage germination of seeds in the organic layer; a thick cap discourages germination.
[g] Control depends on degree of mixing; fine mixing discourages (e.g. rototilling); coarse mixing encourages (e.g. single discing).
[h] Of, Om, Oh represent fibric, mesic and humic organic horizons, respectively.
[i] Will promote Labrador tea and *Vaccinium* species.
[j] Control depends on degree of removal of root systems and stimulation of residuals.

Timing of Treatment

The timing of mechanical site preparation treatments may influence the effectiveness and duration of vegetation control (Ryans and Sutherland 2001). A single site preparation treatment timed when weed species are growing vigorously and able to quickly recover may provide only short-term vegetation control (MacKinnon and McMinn 1988, Bedford and MacKinnon 1996). Properly timed or repeated treatments can improve competition control. For example, aspen suckers more vigorously after scarification conducted during early spring or late fall than after summer scarification (Davidson *et al.* 1988). However, rescarification shortly after aspen suckers will reduce the vigour of subsequent suckering (Ryans and Sutherland 2001). Similarly, for weeds that reproduce primarily from seed from the current crop, site preparation may be timed to avoid the peak seed dispersal period (Bell 1991).

Any of the mechanical site preparation treatment options, such as shearing, mixing, scalping, mounding, or chopping, may be more effective for vegetation control if applied at optimal times determined by the reproductive strategy for the competing species.

Modification of the Site Prepared Area

The modification of an area by mechanical site preparation may be described by the *treatment intensity*, *area coverage* and *disturbance category*.

Delong (1989) describes the following categories of *treatment intensity*:

1. Treatments that create large areas of exposed mineral soil (e.g. ploughing and deep blading). On productive sites dominated by shrub and broadleaf species, "broadcast" treatments have resulted in greater crop tree growth compared with treatments that create small patch or trench-like disturbances (Bedford and Kabzems 2001). These disturbances can drastically change vegetation composition and cover. Disturbed areas will gradually be occupied by pioneer species that seed in or sprout. Mineral soil exposure and increased light can encourage the regeneration of several annual grasses and weed species.

2. Treatments that expose relatively small areas of mineral soil and leave most of the area and vegetation undisturbed. This category includes patch scarification or mounding implements, which provide the least disturbance, and continuous furrow or trencher implements which result in slightly more area of disturbance. Crop trees established on small patch or trench-like disturbances may eventually be overtopped by vegetation growing between the treated areas on productive sites dominated by shrub or broadleaf tree species (Bedford and Kabzems 2001). This type of treatment may result in a mixedwood stand; the vegetation developing on the mineral soil patches will often be different from vegetation on adjacent undisturbed areas. However, if tree species flourish in the mineral soil patches (which is usually the objective), the trees will eventually overtop and alter conditions for shrub and herb species in the adjacent undisturbed areas.

3. Treatments that shear off or push aside trees, shrubs, and slash but leave low-growing plants and organic matter undisturbed (e.g. winter shearing or blading). Part of the site may end up covered with slash piles or debris berms reducing the area available for tree establishment.

Some general effects of treatment intensity include:

- Small areas of disturbance may rapidly develop a canopy of competing vegetation from the adjacent undisturbed areas, particularly on productive sites (Bedford and Kabzems 2001).
- Large areas of disturbance that expose mineral soil may modify surface microclimate and contribute to soil erosion depending on soil textures, topography, and orientation of disturbance patterns.
- When more area is treated, advance regeneration is more likely to be damaged by site preparation.

Area coverage refers to the percentage of the area that is treated by the site preparation equipment. The amount of area coverage is influenced by site conditions, the maneuverability of the equipment, and the expertise of the equipment operator. The occurrence of wet soils, steep slopes, or rough terrain or the amount and distribution of residual trees left after harvest may limit the extent of area coverage. The ability of the operator to recognize site irregularities and adjust equipment settings and/or site preparation patterns to suit the terrain and other site conditions is a key factor in maximizing treatment area coverage.

The cross-sectional profile created by the site preparation implement is used to describe the *disturbance category*. Sutherland and Foreman (1995) describe the following categories to characterize the disturbance to the forest floor by mechanical site preparation implements (Figure 1):

1. **Upland screefing/scalping:** removing or displacing the surface organic (LFH) layer to expose and/or lightly disturb (scarify) the underlying mineral soil.

2. **Lowland screefing:** removing the upper portion of the organic layer without disturbing or exposing the underlying mineral soil.

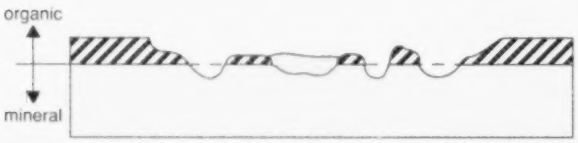
3. **Inverting:** turning the organic layer upside down, either intact or broken, and with or without the underlying mineral soil, over the adjacent and undisturbed organic (LFH) layer.

4. **Trenching:** removing and depositing the organic layer and some underlying mineral soil in berms beside the trench that is produced.

Figure 1. Cross-sectional profiles of six general categories of forest floor disturbance (from Sutherland and Foreman 1995).

Screefing - Upland

Removing or displacing the organic layer to expose and/or lightly disturb (scarify) the underlying mineral soil.



Caution: avoid extensive removal of organic material, particularly on infertile coarse-textured soils with a thin organic layer and on silty or clayey soils prone to glazing (closure of soil pore structure) or frost heave.

Examples of equipment: tractor-mounted blades (straight/angled) or V-blades, light barrel drags, anchor chains or tractor pads, blades/blade attachments (e.g. blade rakes, Young's Teeth), plows (e.g. Cazes, Heppner), disc or cone trenchers (e.g. TTS Delta, Silva Wadell) on shallow settings, and spot scarifiers (e.g. Bräcke or Leno and motor-manual La Taupe scarifier).

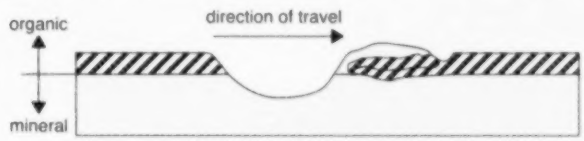
Screefing - Lowland

Removing the upper portion of the organic layer along with partial compaction of the lower portion without disturbing or exposing the underlying mineral soil.

Examples of equipment: shearblades (e.g. Rome, Fleco and Superior V-blade).

Inverting

Inverting the organic layer, leaving it intact or broken (either with or without the underlying mineral-soil capping) over the adjacent and undisturbed LFH layer. The product consists of a screefed or scalped spot or strip and can include mounded mineral soil over mineral soil and/or mounded mineral soil over the inverted LFH.

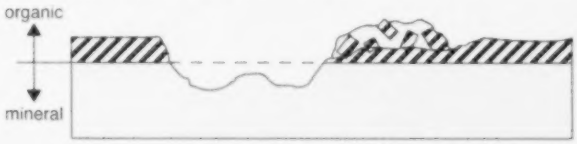


Caution: mounded mineral soil may be prone to periodic desiccation.

Examples of equipment: disc trenchers: spot inverting (e.g. Bräcke, Leno, Donaren 870 H) and continuous inverting (e.g. mold board plows).

Trenching

Removing the organic layer and the underlying upper mineral-soil horizons and depositing it in a berm beside the resulting trench. The layers are in a partially mixed state over the undisturbed organic layer beside the trench.

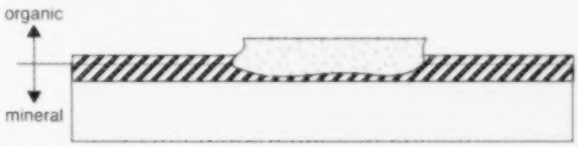


Caution: side berms may be prone to periodic desiccation.

Example of equipment: disc trenchers (e.g. TTS 35/Delta, Donaren 180D, 180L and 280D), cone trenchers (e.g. Silva Wadell), or heavy barrel drags.

Mixing

Incorporating the organic layer into the underlying mineral soil.

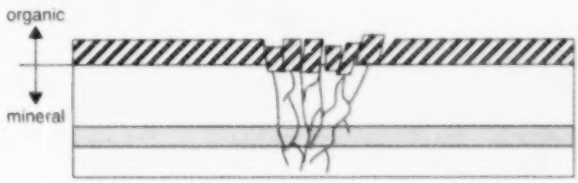


Caution: coarse mixing may encourage non-crop vegetation to resprout.

Examples of equipment: agricultural-type discs (e.g. Rome, Crabe), bedding plows (e.g. Eden, Rome), and rotary mixers (e.g. Madge Rotoclear).

Subsoiling

Fracturing the mineral soil's structure without the mixing of horizons. This may be the first stage of a two-step site preparation process in which the second stage would result in plantable or seedable microsites.



Examples of equipment: ripper teeth or a winged subsoiler.

5. **Mixing:** incorporating the surface organic layer into the underlying mineral soil.

6. **Subsoiling:** fracturing the mineral soil's structure without mixing the horizons.

Table 2 provides a general summary of the types of cross-sectional profiles produced by various site preparation implements. The disturbance categories most commonly produced by mechanical site preparation equipment in Ontario are screefing, inverting, and trenching (Ryans and Sutherland 2001).

Within these general categories, use of an implement may be adjusted to vary the nature of the disturbance to the forest floor. For example, depending on the implement used, the appearance and depth of the microsite profile may be modified by adjusting the speed of the prime mover, the weight of the unit or amount of downpressure, the rotation speed of the implement, or the angle of the implement (Bedford and von der Gonna 1994, Coates and Haeussler 1989). The effectiveness of the treatment will be affected by these adjustments, so the equipment operator should understand the silvicultural objectives and the desired microsite conditions (Wilson 1989).

Some general effects of the depth of disturbance on competing species are:

- Treatments that leave the surface organic layer intact or compacted create conditions suitable for the establishment of "seed-banking" species (Bell 1991, Sutherland and Foreman 1995).
- Treatments that remove the surface organic layer and expose mineral soil create conditions suitable for the germination of "windblown" seed (Bell 1991, Sutherland and Foreman 1995).
- Partial or coarse mixing of the surface mineral and organic layers can stimulate rather than reduce vegetative sprouting (Bell 1991).
- The influence of scalping and inverting treatments depends on the composition of the mound (i.e. sequence of mineral soil and organic layers), depth of mound created and the depth of rooting of the competitive species (McMinn 1984, Bedford and von der Gonna 1994, Bedford and Kabzems 2001). Sprouting can be enhanced on thin mineral caps on inverted humus mounds. Where soils are of medium texture, deep scalping may help by removing roots of competitive species (McMinn 1984).

Specific effects of mechanical site preparation on common competitive plant species are summarized in the Appendix.

Implements to Create Desired Microsites

When preparing a mechanical site preparation plan for a specific area, the following steps should be included to consider how equipment selection and treatments will influence the development of competing vegetation:

1. Determine the microsite conditions (i.e. disturbance categories, desirable microsite distribution and abundance) needed to meet silvicultural objectives (see Figure 1).
2. Identify potential competitive species for that site and their modes of reproduction (see Appendix).
3. Evaluate the relative influence the types of mechanical soil disturbance will have on the key competitive species (see Table 1).
4. Select the site preparation implement, techniques, and timing that will create the desired mechanical disturbance to reduce the vigour and abundance of key competitive species (see Table 2 and Appendix), while still achieving silvicultural objectives at a reasonable cost.

The choice of equipment, techniques, season of treatment, and site preparation patterns will vary by site and silvicultural objectives. Numerous trials have been conducted to assess the utility of various pieces of equipment on different sites to achieve specific objectives (Jacobs and Hollstedt 1994). A thorough discussion of biological considerations and site preparation results on sites in northwestern Ontario can be found in Sutherland and Foreman (1995). Before widespread introduction of a new site preparation tool, equipment suitability and treatment effectiveness should be assessed carefully (see Sutherland 1986).

Below are brief summaries of the basic types of site preparation implements (i.e. drags, blades, plows). They have been compiled from comprehensive reviews of site preparation equipment provided in Smith (1979 and 1981), Coates and Haeussler (1989), Ryans and Sutherland (2001), and additional sources where noted. They are grouped using the categories of Ryans and Sutherland (2001): implements that provide primarily soil treatments and those that provide above-ground treatments with minimal disturbance to the forest floor. The focus of these summaries is to provide information concerning the type and intensity of the disturbance created, general impact on vegetation, and specific site constraints that may limit the use of the implement. Original documents should be consulted for detailed descriptions of the types and models of site preparation equipment, their main features, working principles, general use, advantages, and disadvantages.

Soil Treatment Implements

Blades and Plows

Blades (e.g. straight, angle and v-blades) and plows (e.g. Cazes and Heppner) remove a portion of the organic layer and direct surface debris to the sides of the blade (into "windrows"), resulting in a *screefed* soil profile. The skill of the operator is key to ensuring adequate mineral soil exposure without scraping too much soil into the windrows. Existing competing vegetation is uprooted or sheared off and piled in the windrows. These implements are not recommended on sites with broken or rugged terrain, boulders and rocks, frequent high stumps, shallow soils and thin duff layers, or very wet soils. Removing top layers of organic matter and mineral soil may lead to significant nutrient loss on low productivity sites (e.g. coarse sandy soils).

Disc Trenchers

Disc trenchers consist of two rear-mounted, toothed rotating discs that range from simple machines with passive (i.e. non-powered) discs to more complex machines with hydraulic downpressure and powered discs. The depth and width of the trench produced by passive disc trenchers depends on the weight of the scarifier and angle of the disc. Powered disc trenchers have hydraulically powered discs, continuous variable downpressure, and rotation speed that can be adjusted to accommodate a variety of site conditions. Depending on adjustments to the implement, treatments may result in *trenched*, *screefed* or *inverted* profiles. With continuous furrows, a variety of planting sites are produced, so a planter can choose the best microsite. Orientation of the furrows may be an important consideration (Bedford and von der Gonna 1994). The trencher produces three general microsites: berm, hinge, and trough. Depending on site conditions, each microsite offers different advantages and disadvantages influencing crop tree establishment, and the effect on crop tree performance may be dramatic (Bedford and von der Gonna 1994). Some disc trenchers can also be used to create scarification patches rather than continuous furrows. Because of their versatility, disc trenchers are used extensively in northern Ontario. Disc trenchers do not work well on wet sites with duff depths greater than 20 cm; shallow, rocky or excessively stony soils; or sites with heavy slash or high stumps.

Table 2. Site preparation implements listed by the type of cross-sectional profile they generally produce (after Ryans and Sutherland 2001).

	Type of Cross-sectional Profile					
Implement	Screefing	Lowland Screefing	Inverting/ Mounding	Trenching	Mixing	Subsoiling
Straight/angle blade	X					
Shearblade/ V-blade		X				
Light drag units (e.g. tractor pads, small barrels)	X					
Young's teeth	X					
Plows	X					
Disc trenchers	X		X	X		
Cone trenchers	X			X		
Patch scarifiers	X		X			
Mounders	X		X			
Mold board plow			X			
Heavy drag units (e.g. heavy barrels)	X			X	X	
Disc harrows					X	
Bedding plows					X	
Rotary mixers					X	
Ripper teeth/subsoilers						X

Cone Scarifiers

Cone scarifiers create either *trenched* or *screefed* profiles, similar to powered disc trenchers, but they have two rotating cones with teeth over the surface of the cone (whereas a disc trencher has teeth only on the periphery of the disc). Cone angle and downpressure may be adjusted to vary the depth and slope of the trench that is produced. Ryans and Sutherland (2001) report that cone scarifiers may be used to create plantable microsites in shallow-soiled sites with extensive bedrock.

Patch Scarifiers

Patch scarifiers are "scalper" type implements and are available in a number of configurations. This equipment has a series of toothed or "mattock" wheels, which have gouging or scalping capabilities. These implements prepare *spot inverting* profiles with mineral soil seedbeds in intermittent *screefed* patches alternating with inverted patches of organic matter. Patch spacing may be modified to help control seedling spacing. The intermittent nature of the screefed patches may be desirable under conditions where a continuous trench could cause soil erosion.

These implements may provide limited control of competing vegetation although patches may be too small to provide effective control of vigorous competition. Patch scarifiers are poorly suited to sites with shallow soils or rocky or broken terrain and sites with thick organic layers, heavy clay soils, or heavy slash.

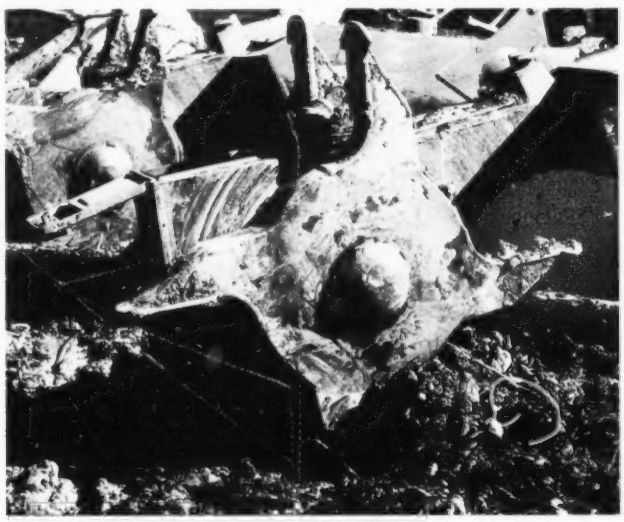
Mounders

Mounding equipment prepares the site by scalping off a patch of the organic layer and underlying mineral soil and inverting it to form a mound creating both *screefed* and *inverted* profiles. The mounds may be mineral soil over mineral soil or mineral soil over organic material. Soil mounds commonly have increased soil temperature, improved nutrient conditions in the inverted duff layer and reduced competition (McMinn 1984). The nature of the capping on the top of a mound (i.e. material and depth) is important for vegetation control and for regulating the temperature and moisture relationships within the mound. Humus-enriched capping does not effectively prevent encroachment of vegetation, and shallow mineral soil caps will not prevent vegetative suckering within the mound (Bedford and von der Gonna 1994). Fine-textured mineral soil caps may actually dry out more quickly and shed or evaporate moisture at the surface, producing drier conditions than in a mound capped with sandy material. However, the long-term effects of mounding on seedlings are not well documented (Sutton 1991).

Drag Scarifiers

Drags consisting of various combinations of barrels, anchor chains, and tractor pads have been used extensively in northern Ontario. Various weights and configurations of drag units can be used to deal with a variety of site conditions, especially variations in slash loading and depth of organic

Features of the disc trencher, such as disc angle, downpressure or weight, can be adjusted to vary the depth and width of the site prepared trench. (photo by R.G. White)



Tines on the mattock wheels of a Bracke cultivator. A seeding unit may be attached to the implement to apply seed as the scalps are prepared. (photo by R.G. White)

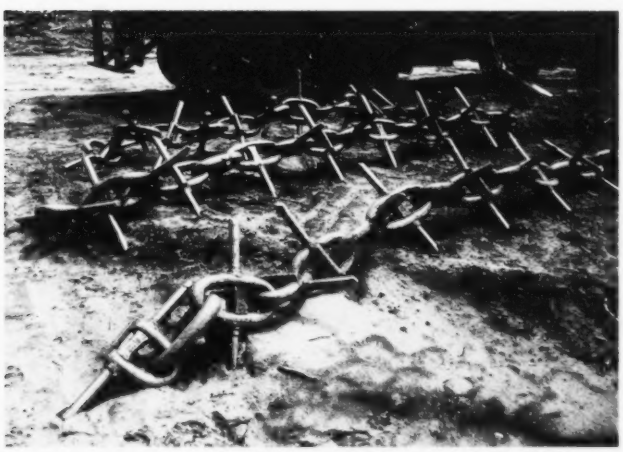
material. This equipment is designed to gouge a continuous furrow of exposed mineral soil (*screefed* profile), break up and redistribute forest debris, and align slash that improves worker access. Strings of drags are attached to draw bars to create multiple furrows in one pass. These units cannot be raised to make discontinuous furrows on erosion-prone slopes, and they are not effective for reducing grass and heavy brush competition, which on competitive sites may quickly reinvade furrows from the sides.

Mold Board Plows

This plow creates an *inverted* planting microsite and was developed primarily for afforestation in southern Ontario, particularly for sites with a heavy sod layer. It has a leading coulter wheel that cuts through the sod layer, followed by a trailing plow with a mold board that overturns the sod, creating a continuous furrow with a single berm of material.

Agricultural and Forestry Disc Harrows

A variety of discs have been used in forestry for site preparation on relatively level, deep-soiled sites. These discs are usually used as a follow-up treatment after landclearing (e.g. burning, slash piling) or for treating field sites requiring rehabilitation. Discing can break up organic matter and create a *mixed* profile of organic matter with mineral soil. Mixing generally exposes mineral soil, which enhances soil temperature similar to scalping treatments and leaves nutrients immediately available for establishing plants. Double discing is done in some parts of Alberta to mix soil and reduce vegetative competition. With double discing, one pass is performed early in the growing season followed by another pass later in the season. By discing resprouted vegetation, its vigour is reduced. This equipment is not suitable for sites with rough terrain, moderate to heavy slash, many stumps, or shallow or stony soils.



Spiked anchor chains may be used alone or in combination with other drag implements, such as sharkfin or flanged barrels and tractor pads. (photo by R.G. White)

Flanged (foreground) and sharkfin barrels (attached to bulldozer). Various sizes, weights and arrangements of drag components may be attached to drawbars and pulled behind tractors or skidders. (photo by R.G. White)

Excavators

Excavators, with attachments such as rakes, buckets and discs, may be used to move slash and *mound* mineral soil to create suitable planting spots. Although the use of excavators is expensive, they offer versatility in dealing with a variety of difficult sites (e.g. sites with thick humus, steep slopes and many high stumps). On wet sites, excavators can be used to create large mounds for planting. However, if other types of mechanical site preparation equipment are suitable for dealing with existing site conditions, they are likely more cost effective than excavators.

Above-ground Treatments

Shearing and Clearing Blades

Shearblading is used for *screefing* on lowland sites. Sites are treated when the ground is frozen, with the objective of removing the upper portion of the organic layer (e.g. sphagnum moss) and partially compacting the lower portion. The treatment produces corridors of screefed microsites for planting or live moss seedbeds for natural seeding.

Clearing blades are used to remove small trees, brush and other debris in preparation for a stand conversion project.

Choppers

Choppers are used to control brush competition and lightly cultivate the soil. Chopping equipment is pulled behind a prime mover and usually consists of a drum or series of drums covered with blades or teeth. Choppers break up and flatten small trees and shrubs. Vegetation that is not brittle tends to spring back instead of being severed. Therefore, the chopping action is most effective when vegetation is frozen or very dry. On frozen ground there will be no soil cultivation; treatment during the dormant season may encourage resprouting of some shrub species. Choppers can be easily damaged in rocky conditions and are not effective in areas with high stumps.

Rakes

Rakes are used to pile harvesting debris and minimize disturbance to the forest floor. By minimizing disturbance and keeping much of the woody debris on the site, site productivity will be maintained.

Summary

Successful silvicultural prescriptions require clear objectives and an assessment of site constraints that could limit success. Often prescriptions will include the use of mechanical site preparation to improve the distribution and abundance of desired microsites. Different microsites can be created with the use of various types of site preparation implements and will influence the regeneration of both desired and competitive species. As part of a vegetation management strategy, the silvics of competing species and their response to disturbance should be considered when selecting mechanical site preparation equipment and techniques.

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Appendix

Response of selected competitive vegetation to mechanical site preparation (from Bell 1991, Buse and Bell 1992, Arnup *et al.* 1995, OMNR 1997).

Species	Response
Trees and Shrubs	
Mountain maple (*Acer spicatum*)	• The main mode of reproduction is from sprouts originating from the stem at the root collar. These stems sometimes grow laterally underground. Plants spread aggressively by this means and by layering to form dense clumps. This species does not produce root suckers or spread by root cuttings. • This species is shallow rooted; roots spread out and remain almost entirely along the interface between the organic and mineral soil layers. To eradicate mountain maple, uproot the entire plant. If stems are simply bent over, trampled, or severed at the root collar, sprouting will occur. For example, discing without follow-up treatment has resulted in an increase in biomass. • Seeding from the current seed crop plays a minor role in maintaining established populations.
Green alder (*Alnus viridus* var. *crispa*)	• Stem sprouting is the dominant form of reproduction. Plants will sprout from the stump if only the aerial portions of the crown are severed. If plant roots are removed, alder competition should be reduced. • This species has not been found to be a component of long-term soil seed banks.
Speckled alder (*Alnus incana* ssp. *rugosa*)	• This species reproduces from sprouts, layering, underground stems and suckers but perpetuates and spreads mainly from sprouts. Reproduction from root suckers is considered to be of minor importance. Stems that are bent and not severed by site preparation treatments will sprout vigorously. Stems in contact with or partially covered by soil will layer and produce new aerial shoots along their length. Alder stems completely severed from the root system will die. • Seeding occurs from the current seed crop, and mineral soil is the preferred seedbed.
Serviceberries (*Amelanchier* spp.)	• Serviceberries may reproduce from root suckers, sprouts, or stolons to form dense thickets. Some species have been shown to reproduce from root cuttings. • Treatments that sever only above-ground portions of the plant may result in increased biomass. Increases in biomass have resulted both where discing was used and where no site preparation was applied. • Seeds from this species are spread almost entirely by animals and birds and may become part of the soil seed bank.
White birch (*Betula papyrifera*)	• Regeneration is primarily by seed from the current seed crop, although birch can regenerate by sprouting from buds at the base of the tree. (Sprouting is more prolific in young trees.) • The light seeds of birch are spread by wind and readily seed into areas where mineral soil is exposed by site preparation. Site preparation treatments that expose mineral soil or mix the organic layer with mineral soil provide an ideal seedbed for germination and establishment. Seeds may remain viable in the forest floor for up to two years if moisture content is low but rapidly lose viability in moist conditions. The small seedlings are fragile and sensitive to moisture, light and seedbed conditions. Shade often improves initial survival. Most seedlings become established the first season following disturbance.

Appendix cont.

Species	Response
Trees and Shrubs	
Red-osier dogwood (*Cornus stolonifera*)	• Seeds are spread mostly by birds and small animals. This is a seed-banking species, and seeds can remain dormant for several years until conditions become favourable. Exposure of mineral soil may stimulate germination of buried seeds. Germination appears to be best when seeds are slightly buried beneath the soil surface. • This species reproduces vegetatively through stem or root collar sprouts, layering, root suckers and stolons. Plants damaged during site preparation will sucker or sprout from roots and stem bases. Buried stem fragments will root, especially if they are in moist or wet soil or are cut during the dormant season.
Beaked hazel (*Corylus cornuta*)	• Reproduces primarily by sprouting from either aerial or underground stems. Sprouting from underground stems is most important for the expansion and regeneration of colonies. Sprout formation increases following damage to the main stem and/or after the plant is well established. Stem sprouts have been reported to occur 3 m or more from the original stem. • If site preparation does not destroy or remove underground stems, hazel will sprout back, and the number of aerial stems will eventually increase, resulting in dense thickets. Deep scarification and disc trenching have reduced abundance and cover of hazel. Discing may expose underground parts, setting back growth for several years. • Seeding occurs from the current seed crop, but seedlings are not abundant in nature due to rodent predation or damage by insects and fungi.
Balsam poplar (*Populus balsamifera*)	• Reproduces from root suckers, stump and root collar sprouts, cuttings, and seed. Regeneration by suckers is considered to be most important. Most suckers grow from roots in the top 2 cm of soil. Mechanical site preparation will promote suckering by increasing soil temperatures. Trees cut or damaged by site preparation will sprout from the stump or sucker from roots. Branch fragments buried as a result of soil disturbance have a high likelihood of regenerating, but they must be well buried in soil to produce aerial shoots. • Reproduction from seed permits colonization of areas where the species didn't occur before. Seeds remain viable for only a few days and germinate immediately after dispersal if seedbed conditions are favourable. Mechanical site preparation creates a favourable seedbed if mineral soil is exposed. Moist mineral soil provides excellent conditions for seed germination and for the survival of young seedlings, which are extremely susceptible to drying.
Trembling aspen (*Populus tremuloides*)	• Reproduces primarily (and aggressively) by root suckers but also by seed, stump sprouts and root collar sprouts. Most suckering occurs in roots 4–12 cm below the soil surface. Aspen suckers vigorously when the organic layer is disturbed but not removed and root systems are left intact. Ground disturbance improves sucker production by reducing understorey competition, removing debris, and opening the forest floor to allow increased solar heating. • Using treatments that involve a high level of cultivation and remove or destroy roots, such as deep plowing, may control aspen. Damaging roots may encourage the incidence of disease and reduce aspen vigour. Site preparation treatments such as raking, drag scarifying or disc trenching will usually promote suckering, as will shearblading on frozen soils. Site preparation may encourage suckering along site prepared furrows. Scarification in early spring and late fall tends to increase the survival and vigour of aspen suckers. However, site preparation after leaf flush in the spring or re-treatment after aspen suckers may reduce the vigour of subsequent suckers. • Exposed mineral soil provides a favourable seedbed. Seed only remains viable for a short period. For seeding to be successful, it must coincide with sufficiently moist seedbed conditions to allow germination and establishment.

Appendix cont.

Species	Response
Trees and Shrubs	
Pin cherry (*Prunus pensylvanica*)	• This is a seed-banking species, and large quantities of seed may persist in the seed bank for 30 or more years after pin cherry has died out from the stand. Seeds are spread by small mammals and birds. Few seeds germinate beneath a closed canopy; germination occurs in response to disturbance. Once established, pin cherry will reproduce by suckering and basal sprouting. • Above-average biomass of pin cherry has occurred in conifer plantations that have been disced or raked and below-average biomass in plantations that have not been site prepared.
Gooseberries (*Ribes* spp.)	• Seeds of most species of *Ribes* germinate in the spring following seed ripening and after the seed has been dispersed by birds and mammals. Many species are seed bankers. Reproduction may be promoted by mechanical site preparation if seedbeds of moist mineral soil mixed with humus are created. • *Ribes* reproduce vegetatively by sprouting from the root crown and by layering. Site preparation treatments that damage aerial portions of the plant may stimulate sprouting. Plants are especially vigorous on fresh to moist sites.
Prickly rose (*Rosa acicularis*)	• Seeds are dispersed by small mammals and birds that eat the fruit (hip) and pass the seeds. Complex dormancy mechanisms may delay germination until conditions are favourable, spreading the germination of a single seed crop over a number of years. This is a soil seed-banking species. • Once established, this species spreads vegetatively by rhizomes, sprouting and layering. Rhizome cuttings produce both roots and shoots. Any treatment that breaks up rhizomes will increase sprouting. One study showed that even three passes of heavy discing will not kill underground rhizomes. Above-average biomass of rose has been observed on a site in Minnesota that was raked. However, in interior Alaska, prickly rose was more abundant on unscarified sites.
Wild red raspberry (*Rubus idaeus* ssp. *melanolasius*)	• This is a seed-banking species. Natural seed dispersal occurs primarily by birds, small mammals and bears. Some seeds may germinate the year after dispersal, but many remain dormant for as long as 50 to 100 years. Germination of stored or recently deposited seed is the primary means of establishment on disturbed sites, but one year after raspberry starts to seed in, further establishment from seed is almost non-existent. • Once established, raspberry's ability to rapidly develop into dense colonies depends primarily on its ability to reproduce vegetatively. Vegetative reproduction occurs primarily by root suckers from buds on roots and by stem sprouts, usually from basal buds near ground level. • Mechanical site preparation tends to increase raspberry abundance, forming dense patches. It can fragment the root system, resulting in new plants, and can stimulate root suckering. Deep cultivation of raspberry (15–23 cm) cuts the roots of existing raspberries and causes the formation of many suckers. Repeated treatment may control the spread of raspberry by root suckering, but adjacent undisturbed plants will have increased vigour.

Appendix cont.

Species	Response
Trees and Shrubs	
Willows (*Salix* spp.)	• Damaged or cut stems produce numerous sprouts from the stem base or root collar. Layering may also occur if branches are buried in moist soil. If site preparation removes the root system, willow competition should be reduced. However, treatments that only damage stems can stimulate sprouting. • One study found above-average willow biomass occurred on sites that had received a disc treatment, but below-average biomass occurred on sites that had been rock-raked. Windrowing has been used as a treatment to stimulate willow browse production because the mechanical damage to stems results in prolific sprouting. Branch parts buried by soil can root and develop into new plants. • The light seed is distributed by wind and remains viable for only a few days. Mineral soil exposure by site preparation provides the best seedbed for many willow species, since germination of the small seed is inhibited on sites covered with tree litter.
Low sweet blueberry (*Vaccinium angustifolium*)	• Seed is spread primarily by birds, small mammals and bears. Seedlings have a high mortality rate. • Vegetative reproduction occurs from sprouts, underground stems and suckers. Asexual reproduction occurs when rhizomes are cut, and plants may resprout from rhizomes following site preparation.
Velvet-leaf blueberry (*Vaccinium myrtilloides*)	• Reproduces from rhizomes on both mineral and organic soils, if adequate moisture and aeration are available. Site preparation increases abundance by segmenting rhizomes, which then produce new shoots. • Seed dispersal is by birds, small mammals and bears. Seed viability may be low (i.e. 20 to 30%) and may be further reduced after excretion by birds and mammals.
Herbs	
Large-leaved aster (*Aster macrophyllus*)	• Abundance increases following treatments that break up rhizomes of existing plants. Berms of trenches or mounds are not suitable for large-leaved aster, but other aster species may invade these sites. • Not a seed banker; seeds invade from the current seed crop.
Field bindweed (*Convolulus arvensis*)	• This species seeds in on exposed mineral soil that may result from site preparation treatments. Seeds may exist in the soil seed bank. • Asexual reproduction occurs from rhizomes.
Fireweed (*Epilobium angustifolium*)	• Seed is dispersed by wind and small mammals and is the primary means of colonizing a new site. Fresh seed germinates promptly and does not develop a buried seed bank. • Mechanical site preparation produces a suitable seedbed. If mineral soil is exposed when seeds are dispersed (seeds ripen from August to September), high germination rates may occur. Seedlings emerge successfully only from seeds germinated on or close to the soil surface. • Vegetative reproduction is from horizontally spreading fleshy roots. The fragmentation of the root system by site preparation may result in additional plants.

Appendix cont.

Species	Response
Grasses and Sedges	
Blue-joint grass (*Calamagrostis canadensis*)	• Soil disturbance stimulates growth and vigour of Canada blue-joint; plants growing on disturbed soil showed more shoots per clone, more flowering heads, more seeds per head, greater plant height, and higher nitrogen and phosphorus concentrations in tissues than plants on undisturbed areas. Vegetative reproduction occurs from rhizomes. • Exposed mineral soil provides a suitable seedbed for the current seed crop. Seeds are light and easily disseminated by wind. Once it has seeded in, this species spreads primarily by rhizomes. • On mounds in wet sites, blue-joint can become a major competitor. However, mounds capped thickly with mineral soil may inhibit blue-joint regrowth (Bedford and Kabzems 2001). Heavy cultivation may reduce the cover of established plants, but adjacent, undisturbed plants may rapidly invade areas of newly exposed soil.
Other grasses and sedges (e.g. *Carex* spp.)	• There are many grass and sedge species, but information on individual species is limited. Vegetative reproduction occurs primarily by means of rhizomes or stolon-like rootstocks. Information on response to site preparation is limited, but treatments that cut up rhizomes should increase the abundance of these species. • Exposed mineral soil provides a suitable seedbed. Large seed crops occur annually and may be widely dispersed. Seeds of many species occur in the soil seed bank.
Ferns	
Bracken fern (*Pteridium aquilinum*)	• Cover will increase following site preparation except where very thorough plowing, blading, or discing removes underground rhizomes. Any treatment that merely breaks up rhizomes will increase sprouting. Crushing is most effective just prior to full frond stage. • Spores can establish on bare mineral soil.
Bryophytes and Lichens	
Lichens (*Cladina* spp.)	• Heavy site preparation such as trenching and blading may destroy 50% or more of the lichens by exposing large amounts of mineral soil and depositing soil and humus on unscarified strips. Lighter methods, such as Bracke and light drags, cause less damage. By crushing lichen patches, mechanical site preparation creates fragments that are distributed by wind and recolonize disturbed sites (Hollstedt and Harris 1992). A shallow layer of loose soil is necessary for lichens to prosper on rocks. Site preparation techniques causing erosion of soil on rock outcrops will slow lichen regeneration (Hollstedt and Harris 1992).
Feathermoss (*Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis*)	• Harvesting and site preparation in shallow upland black spruce stands in northwestern Ontario increase feathermoss mortality during the first year after disturbance. Two to three years after disturbance, feathermoss populations increase but do not reach pre-cut levels. • Removal of the feathermoss layer to expose the upper mineral soil may stimulate the germination of herbs and shrubs, creating an environment that is not favourable for feathermoss growth (Kershaw *et al.* 1994a).
Sphagnum moss (*Sphagnum* spp.)	• Sphagnum moss decreases following mechanical scarification on lowland black spruce sites when outcompeted by broad-leaved trees, shrubs, graminoids and herbs. Crusty surfaces may develop on exposed humus layers and mineral soils, creating conditions that are not conducive for sphagnum regeneration and growth (Kershaw *et al.* 1994b). • Shearblading sphagnum immediately after winter harvest will help maintain a sphagnum cover. Compaction and disturbance of sphagnum improves black spruce seedbed conditions.

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